Centrality Detector for Collider-Based Experiments

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Outline of the talk

- Motivation.
- Concept.
- Generators.
- Detector parameters.
- Conclusions.

Motivation

Major disadvantages of current centrality determination approach.

- Model based
  Uses Glauber or Glauber-Gribov models, approximates particle production mechanism typically at high eta.

- Biased.
  Uses particles produced in HI collision which creates correlations between centrality parameters and measured physics phenomena.

- Trigger
  Relies on the knowledge of min bias trigger efficiency.

Concept

Direct way to measure centrality is to measure N_{part}

$$N_{part} = 2A - \sum_i A_f^i$$

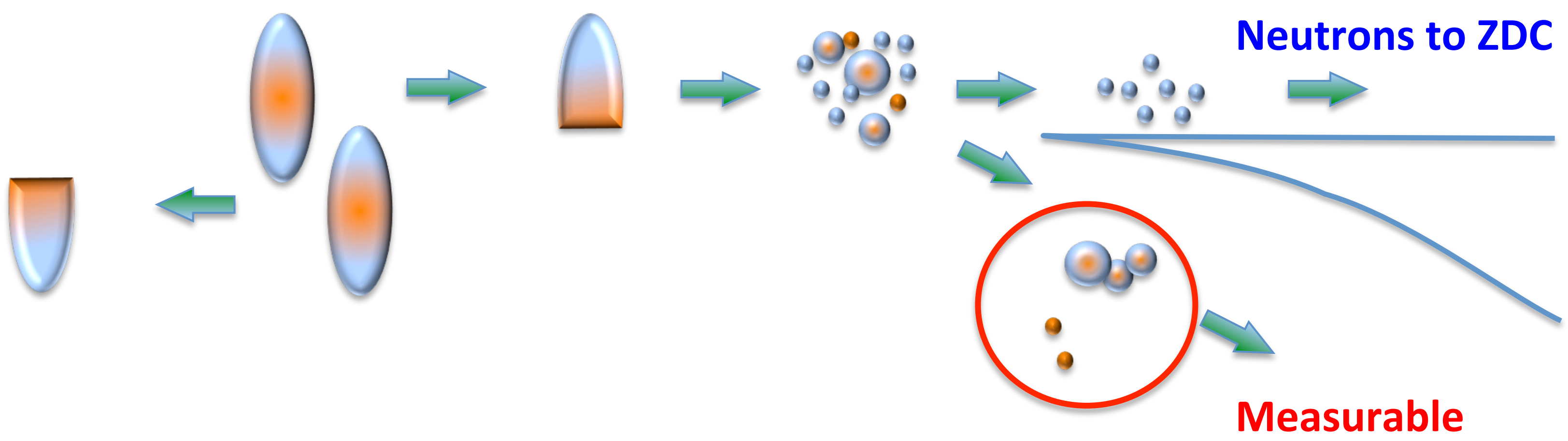
Where A for Au = 197 in the current study and A_f is the mass number of spectator fragment. The sum runs over all spectators on both sides of I.P.

We partially do that by measuring neutrons in ZDC.

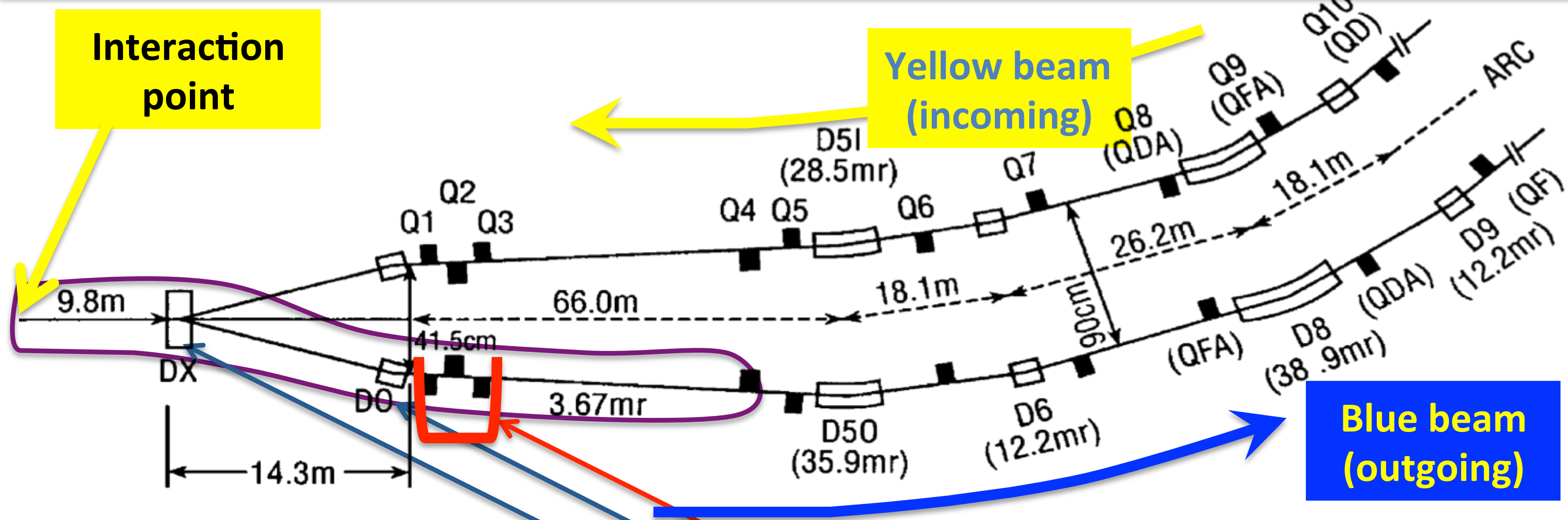
Concept

- Collider magnetic system are nearly perfect mass spectrometer for distinguishing different spectator species based on their mass to charge ratio ~ A/Z.

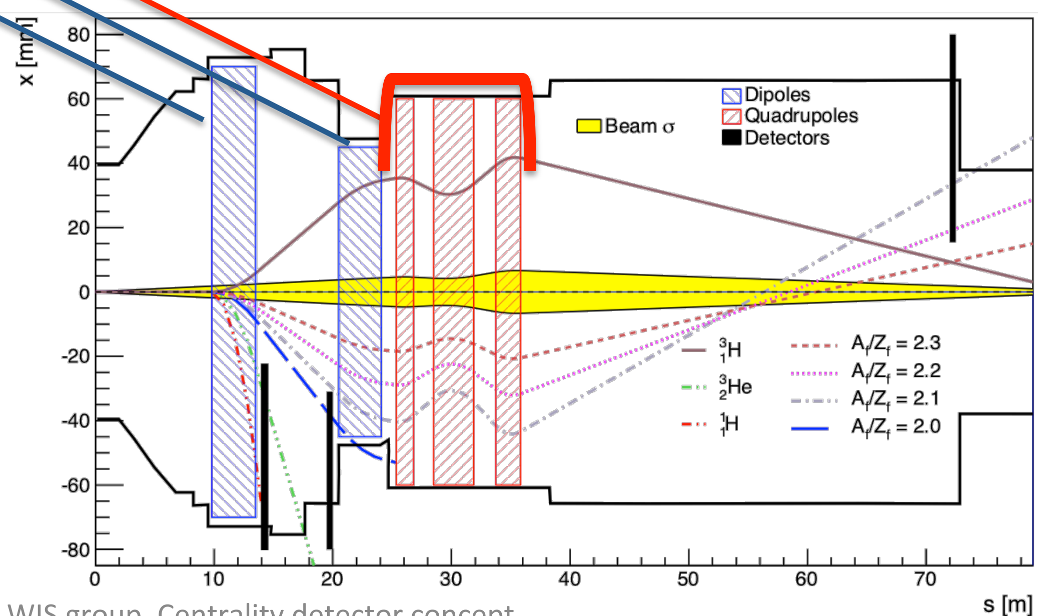
- In a collider an equilibrium particle , $^{197}_{79}$Au remains on an equilibrium orbit. However spectators has lesser mass and hence lesser A/Z ratio.



Equilibrium beam in RHIC



- MAD-X is used for tracing the spectator fragments.
- Doesn't take into account of nuclear fragmentation and is completely ideal case.



Fragment generators

- In an ideal case the expression

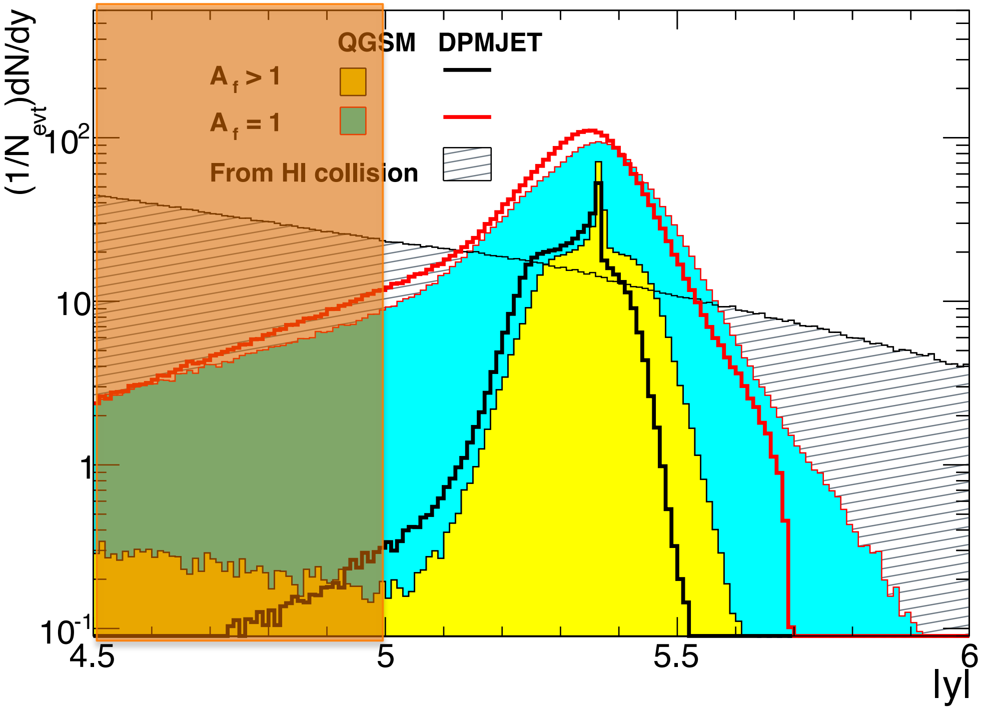
$$N_{part} = 2A - \sum_i A_f^i$$

does not require knowledge about how spectator nucleons aggregate into fragments.

- In reality the detector performance strongly depends on how the remaining part of nuclei fragments.

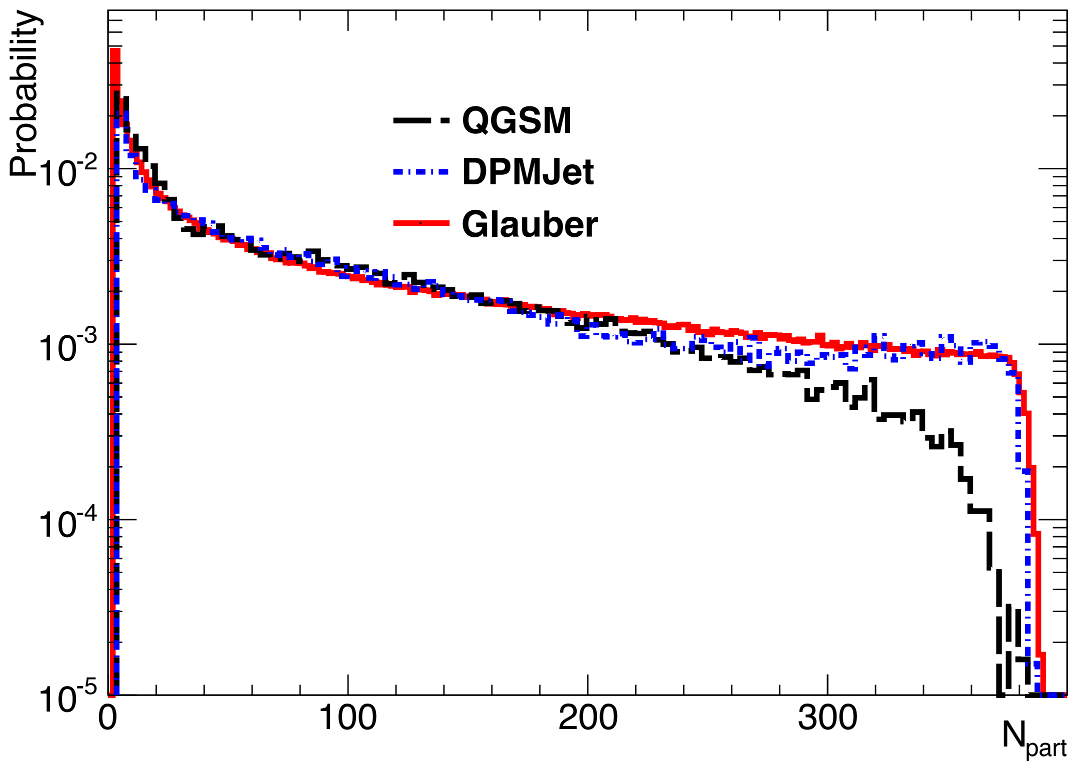
- Two generators are used for further studies: DPMJET and QGSM

Spectator definition



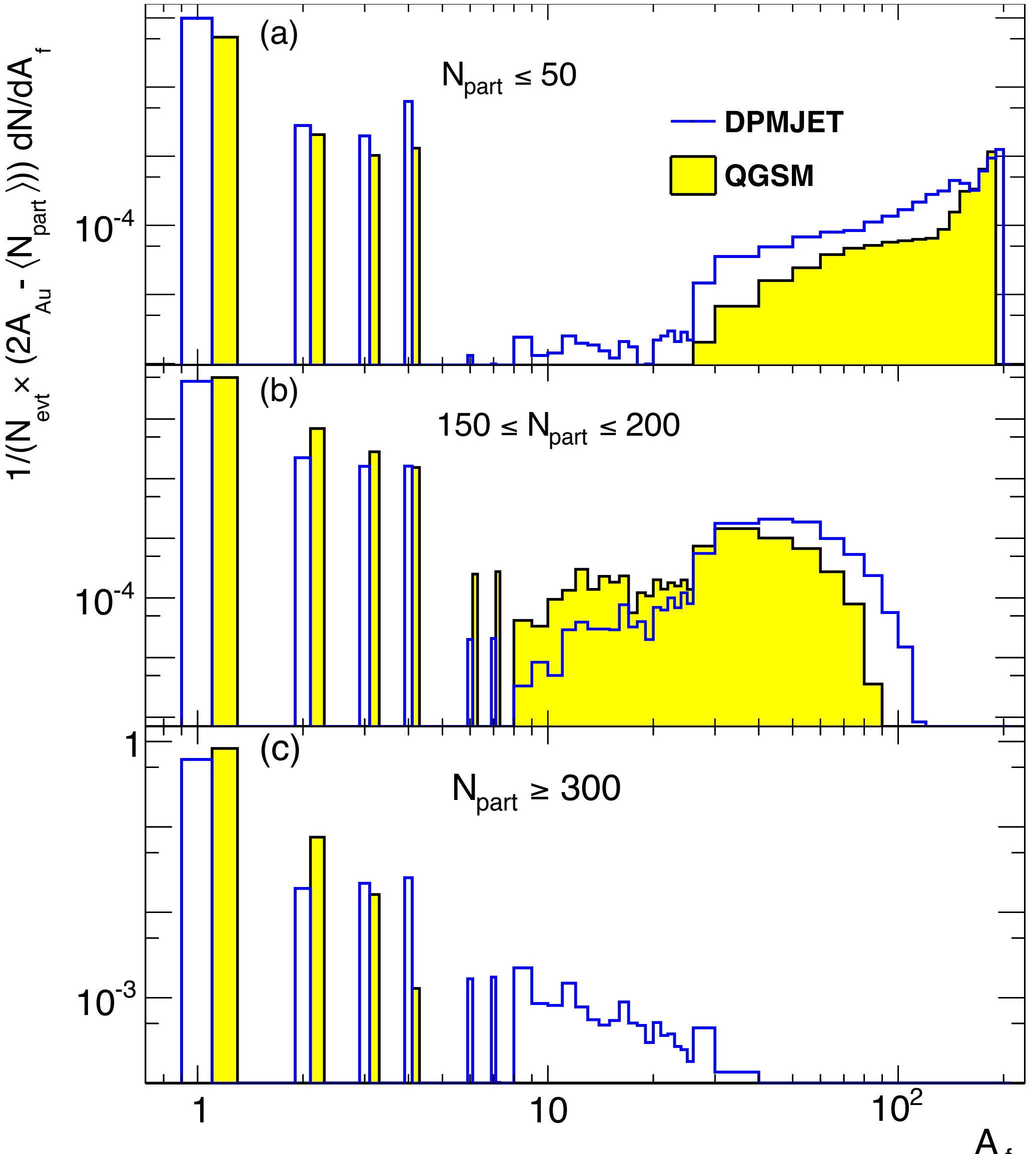
- Rapidity distribution of fragments from two generators are different.
- DPMJET also models produced particles, the QGSM does not. Those particles are the background.
- Particles in |y| > 5.0 with baryonic number > 0 and not produced in HI collisions are considered spectators.

N_{part} distribution



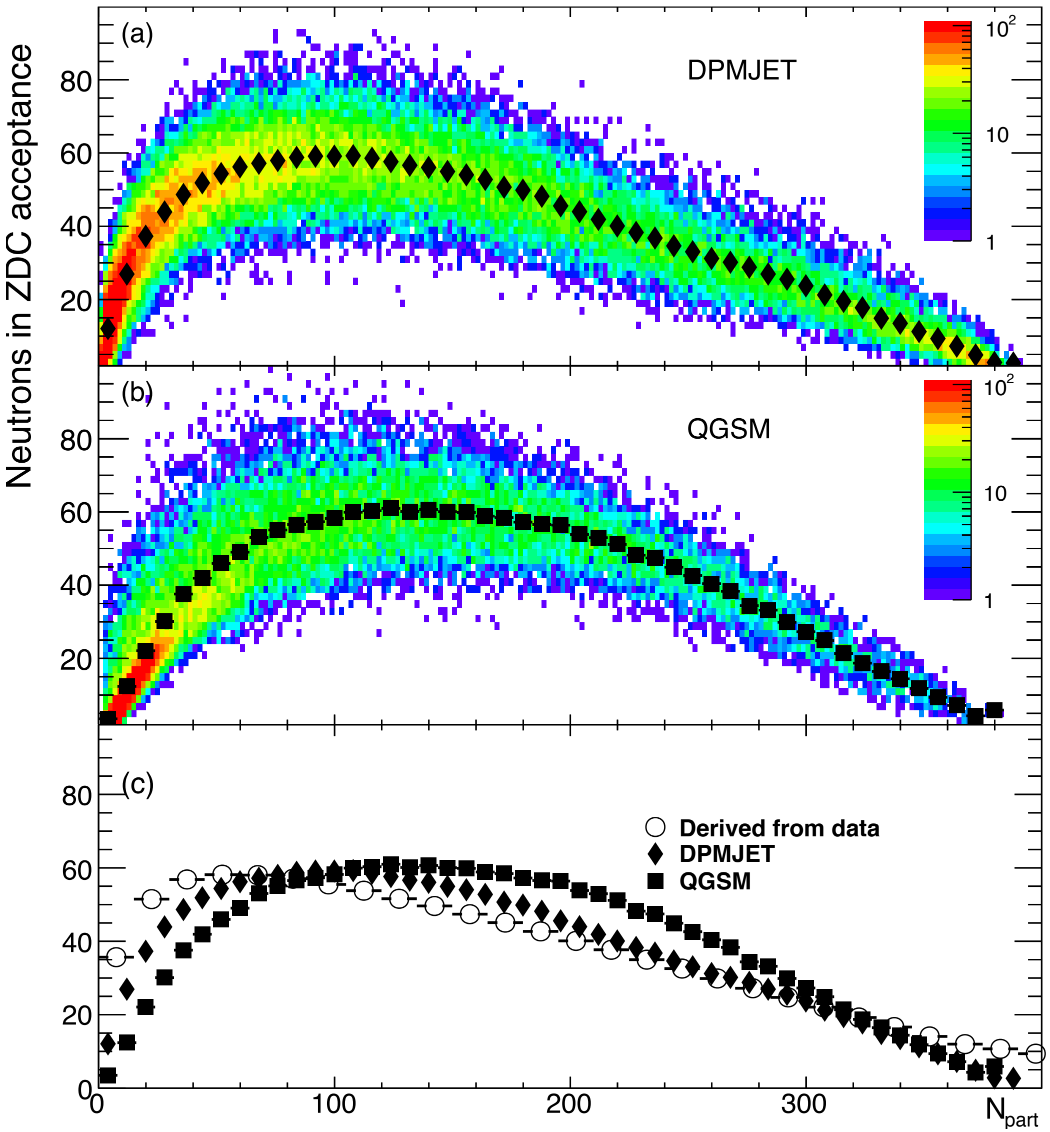
- DPMJET and Glauber N_{part} matches reasonably well.
- QGSM shows significant deviation from Glauber.

Fragmentation



- Significant difference in the fragment mass number in different N_{part} region for both the generators.

Generators comparison with PHENIX data



- We cannot compare all fragments, but we can compare free neutrons in the ZDC.
- Trends are similar, but the agreement is not perfect.
- DPMJET better agrees to data for $N_{part} > 150$.
- In the most peripheral events both models have less free neutrons as compared to data.

Spectator deflection

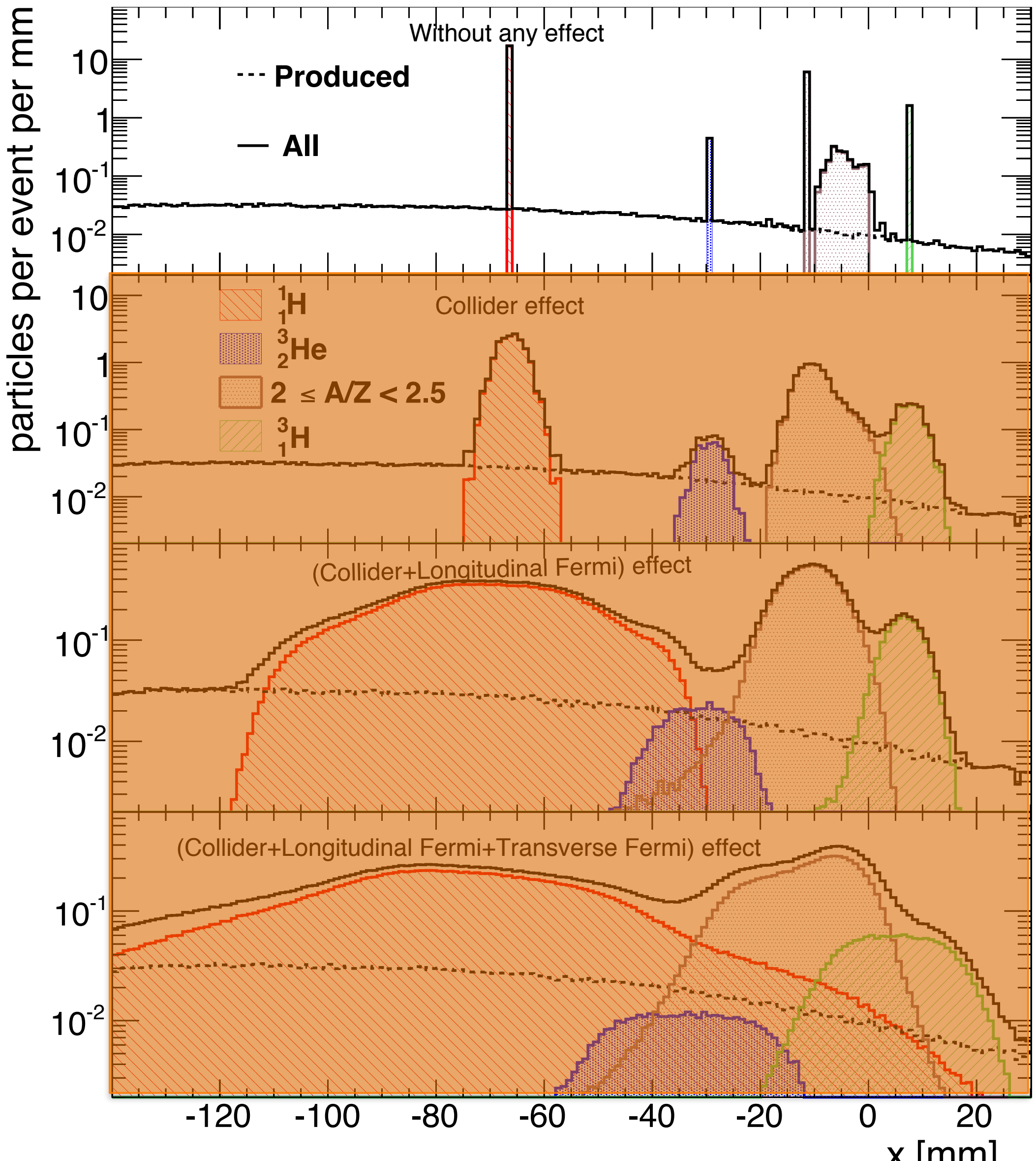
Effects which contribute to the fragment deflection in the detector:

1. Beam dispersions, mainly x (beam spot) and x' (beam angular spread).

2. Fermi motion of the fragments coming from Fermi motion of the nucleons in the nuclei.

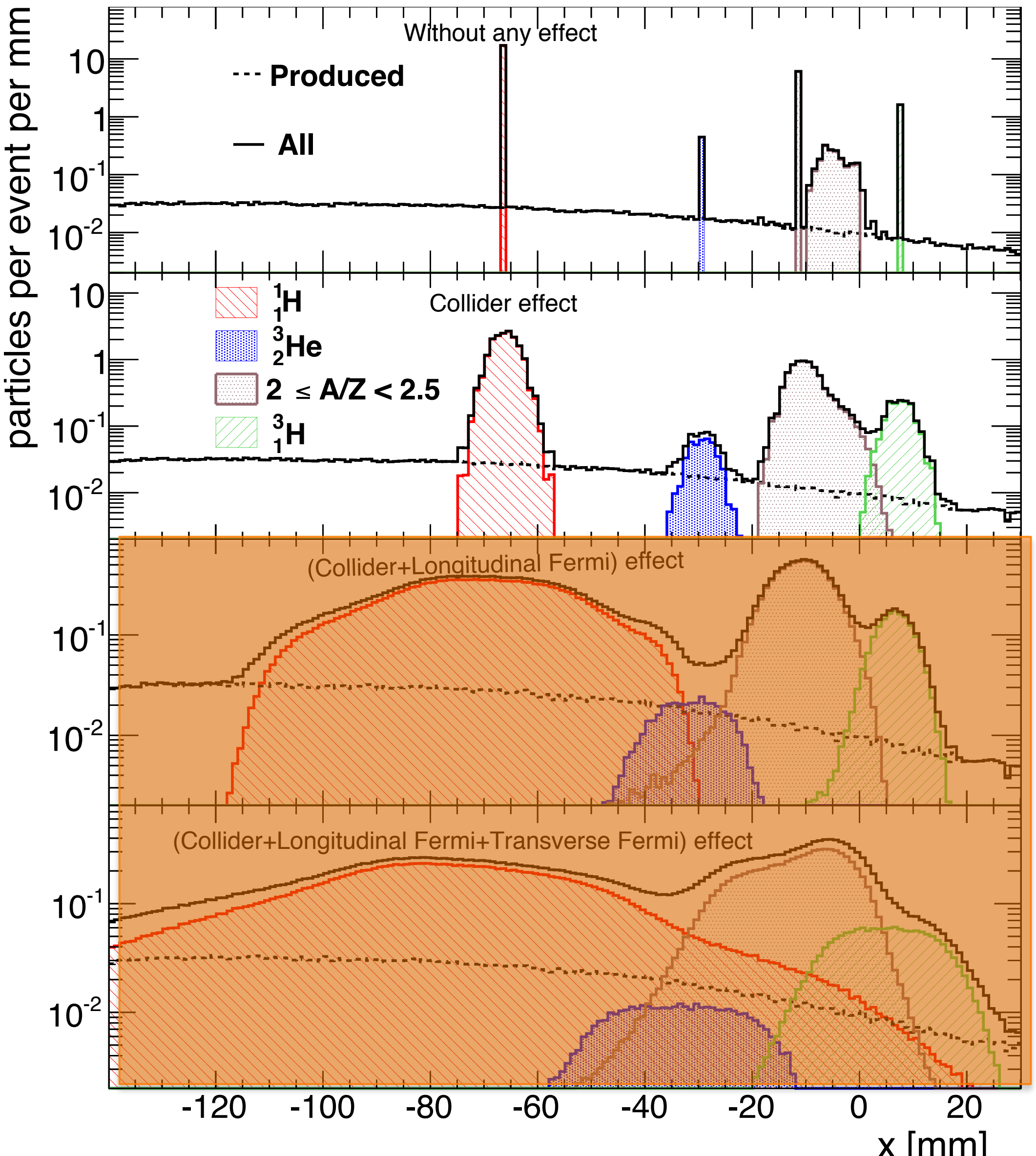
   - It more affects lighter fragments than heavy ones where motion averages out.
   - Longitudinal and transverse Fermi motion will be addressed separately.

Deflection in station 1 (example)



Ideal case, no dispersions.

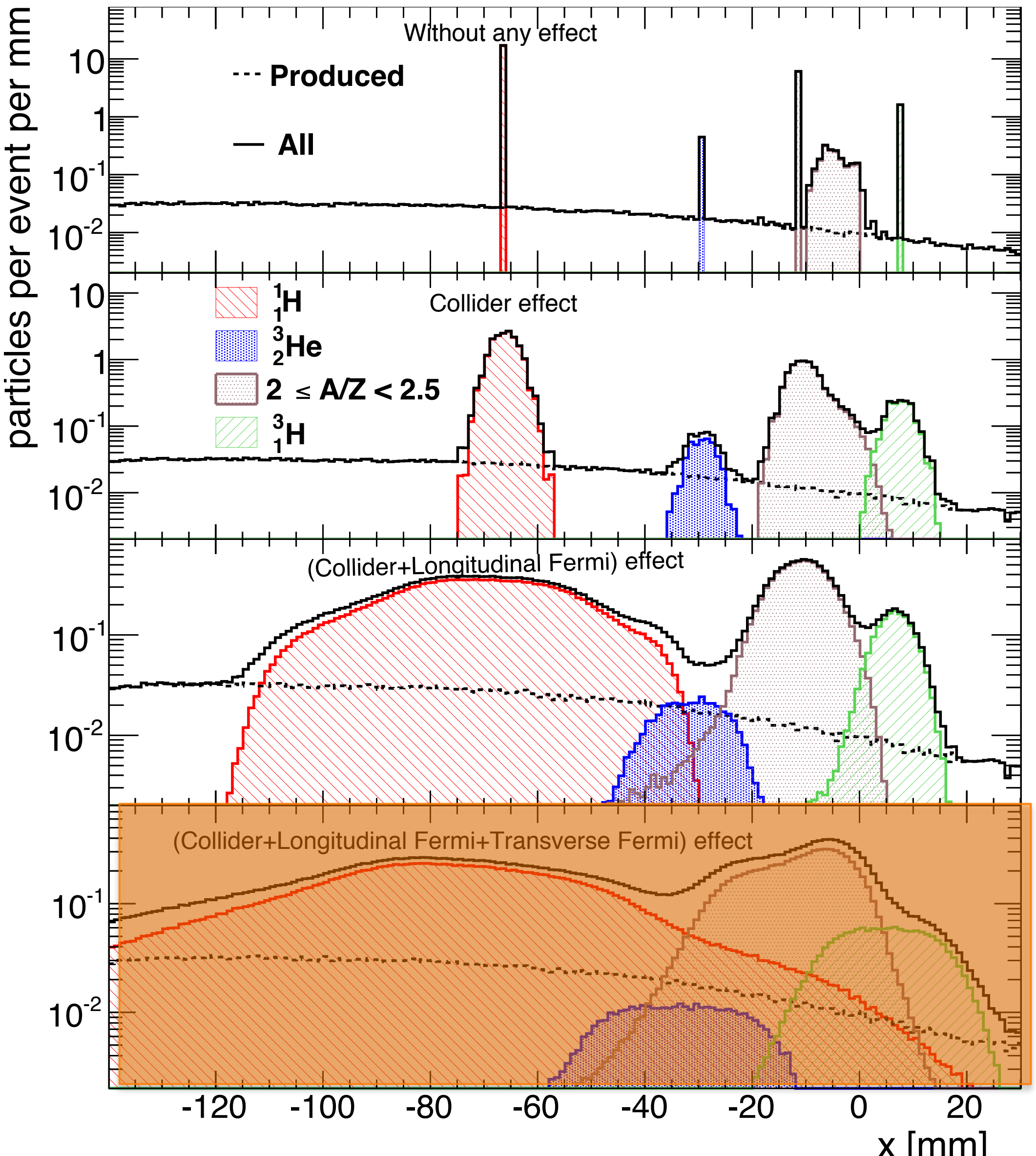
Deflection in station 1 (example)



Ideal case, no dispersions.

Taking into account beam dispersions in x and x'.

Deflection in station 1 (example)

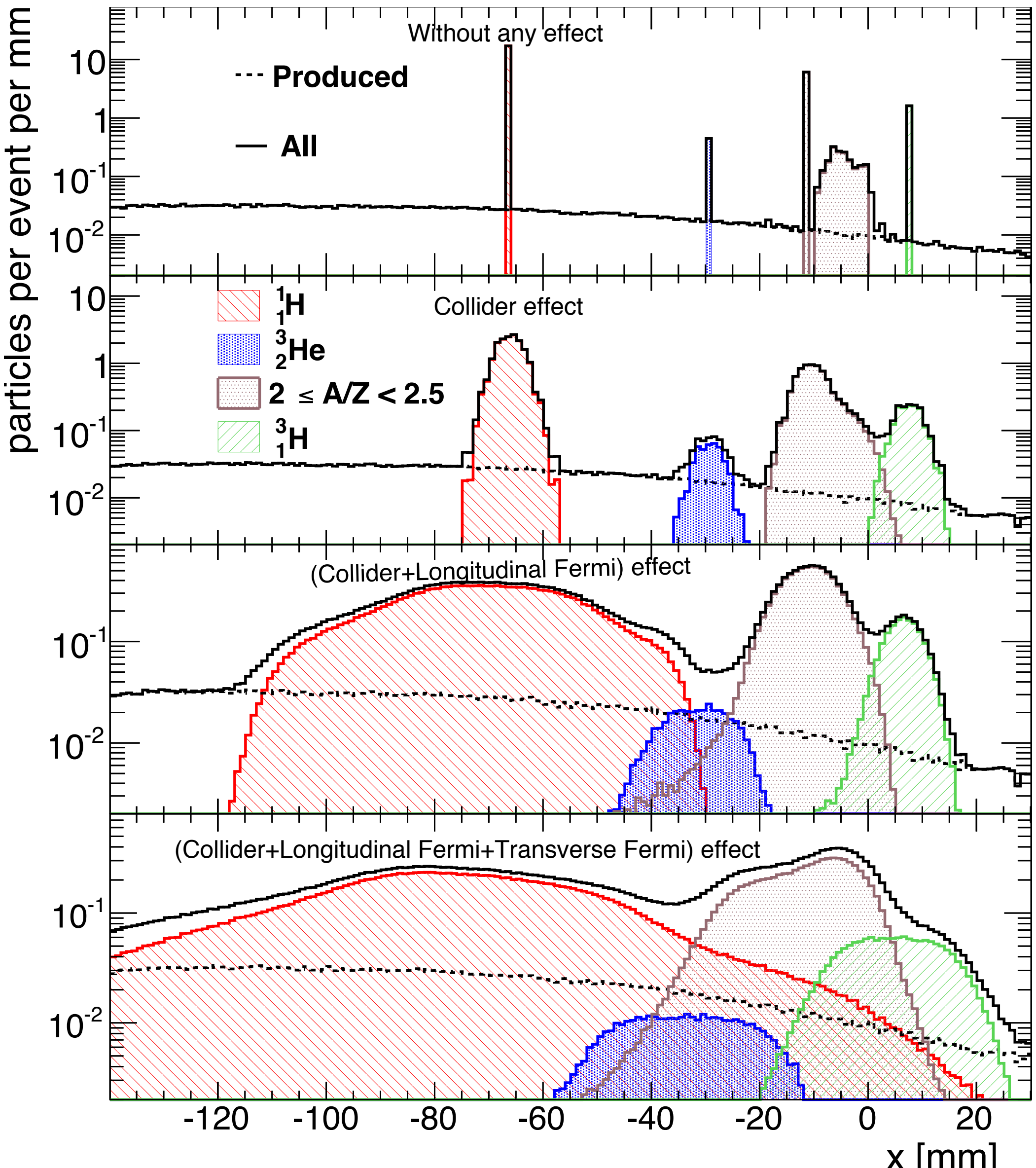


Ideal case, no dispersions.

Taking into account beam dispersions in x and x'.

The same and adding Fermi motion in longitudinal direction.

Deflection in station 1 (example)



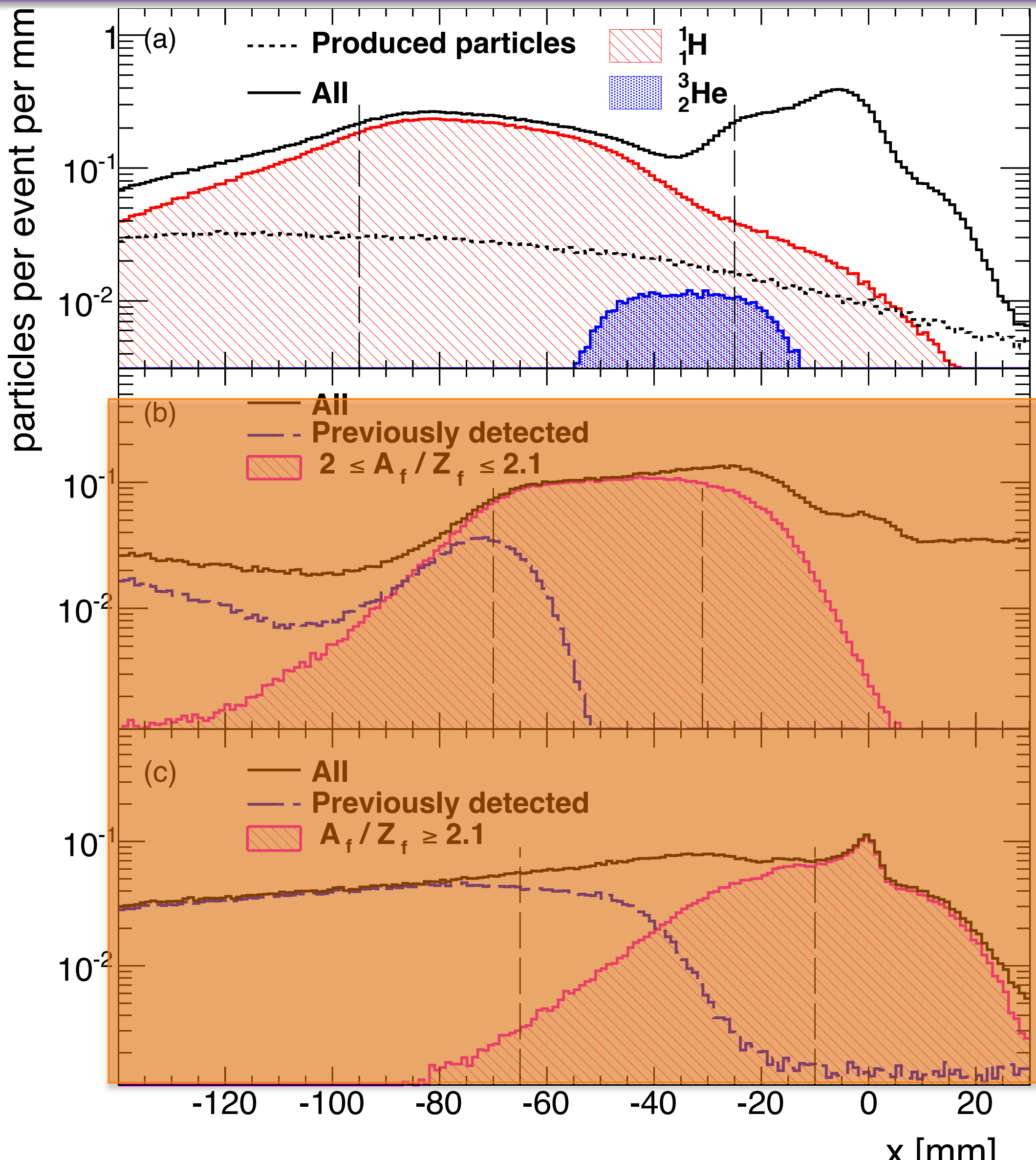
Ideal case, no dispersions.

Taking into account beam dispersions in x and x'.

The same and adding Fermi motion in longitudinal direction.

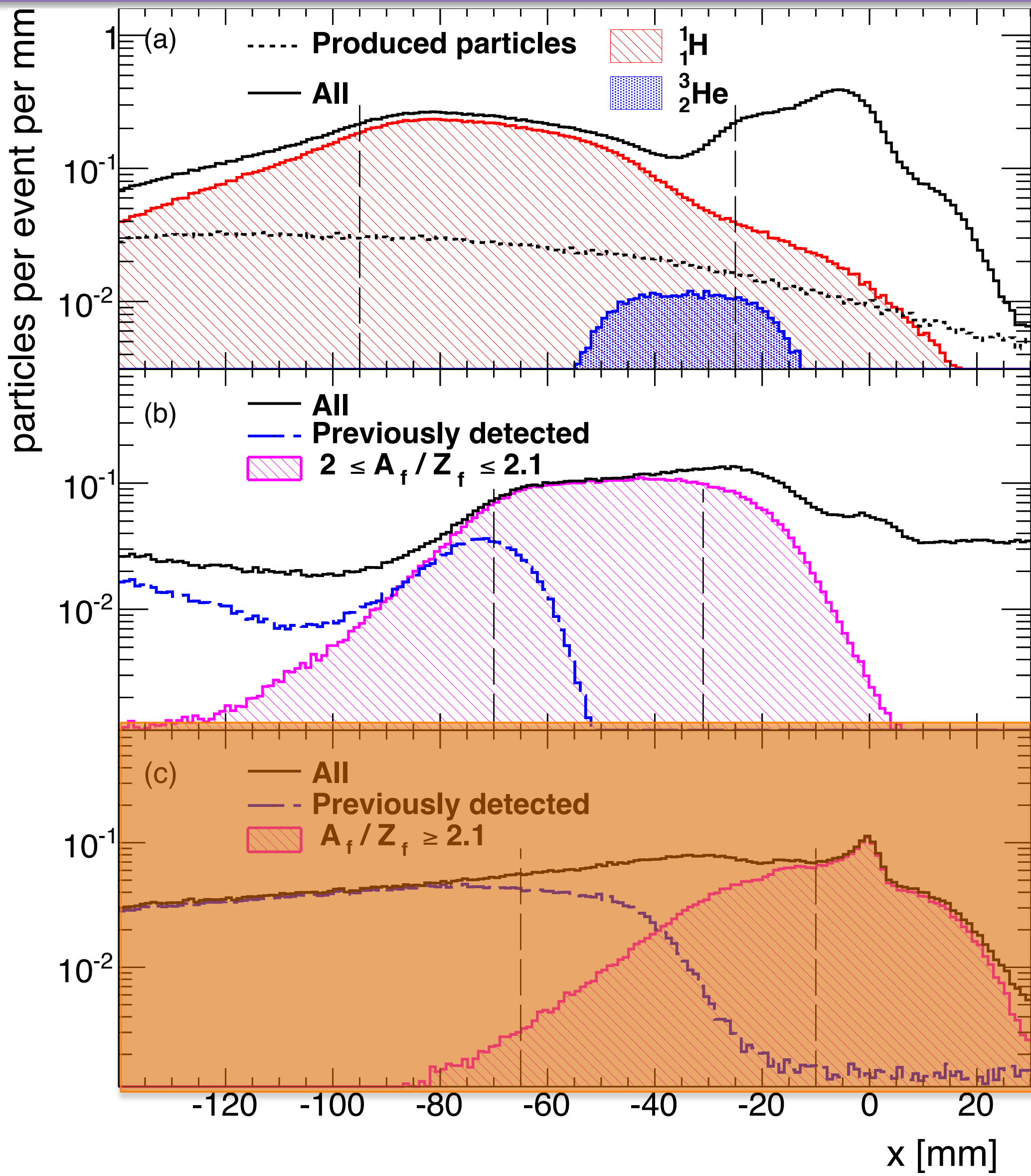
The same, with full Fermi motion.

Deflections in different stations



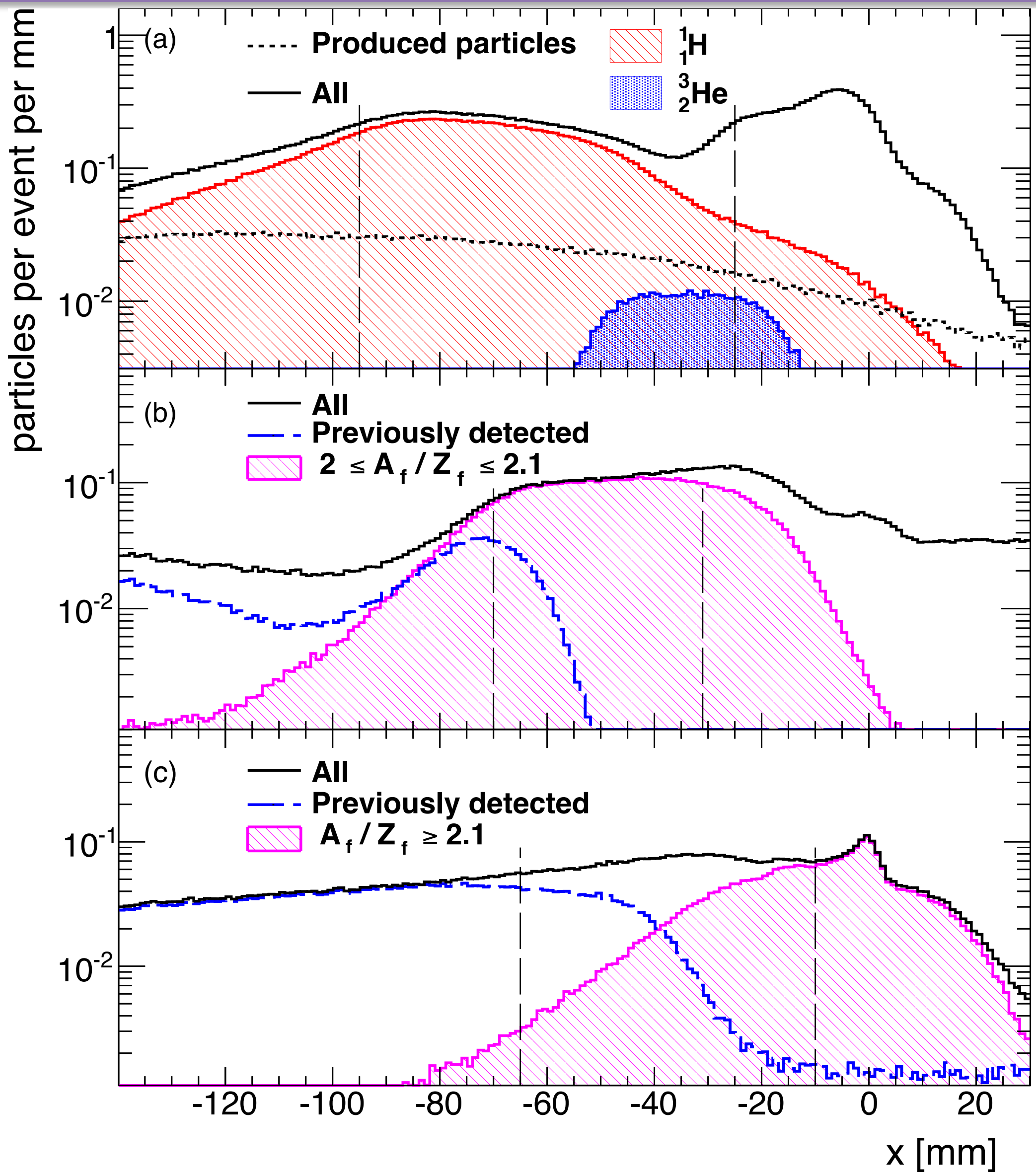
- Station 1 is for protons (red) and He-3 (blue). Same plot as above with all effects in.

Deflections in different stations



- Station 1 is for protons (red) and He-3 (blue). Same plot as above with all effects in.
- Station 2 is for fragments with 2 < A/Z < 2.1

Deflections in different stations

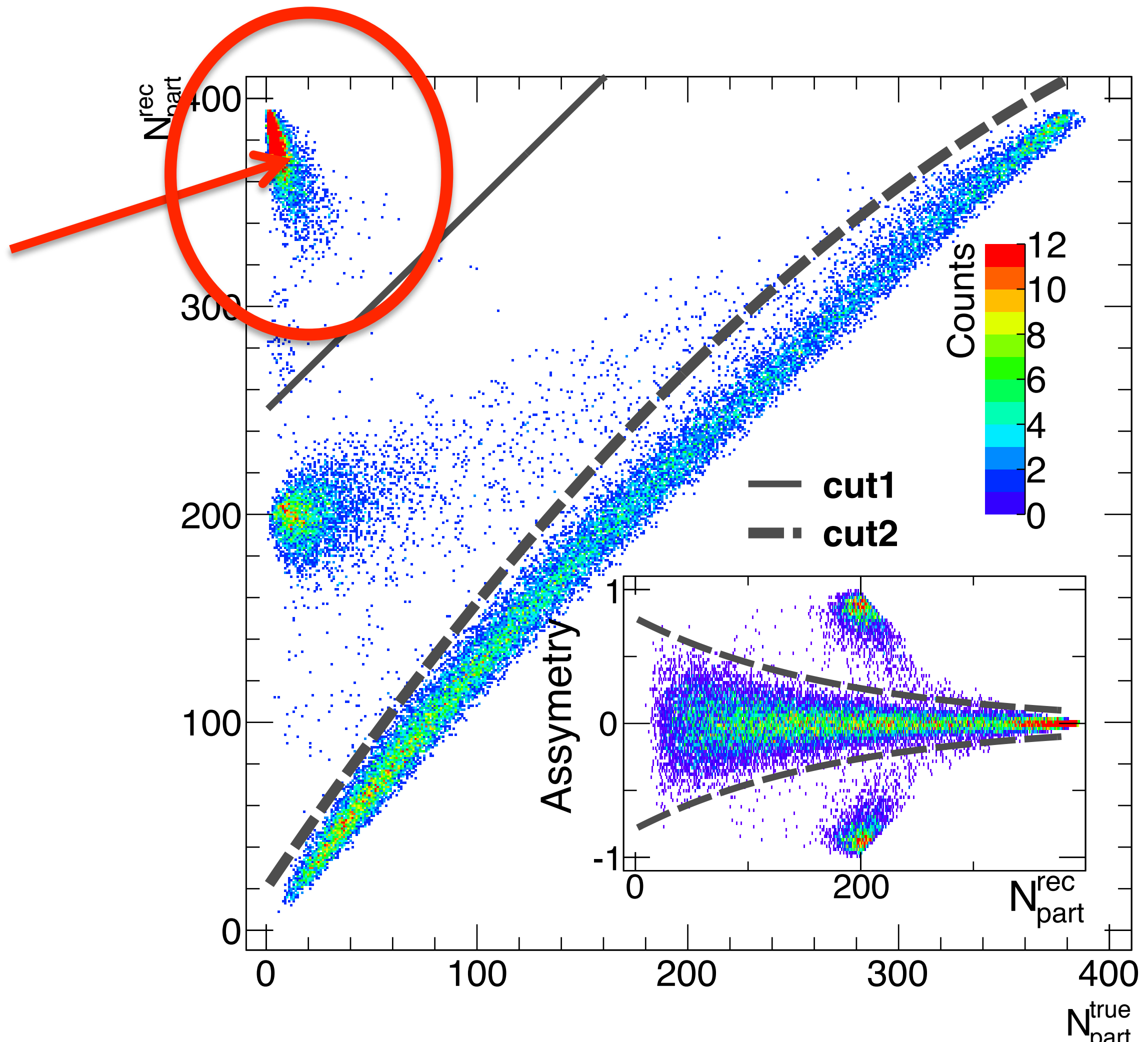


- Station 1 is for protons (red) and He-3 (blue). Same plot as above with all effects in.
- Station 2 is for fragments with 2 < A/Z < 2.1
- Station 3 is for fragments with A/Z > 2.1
- Neutrons are measured by the ZDC and are not shown.

Reconstructed participants

After summing up the fragments in all stations we can calculate the number of reconstructed participants

Failed to detect a heavy fragment on both sides

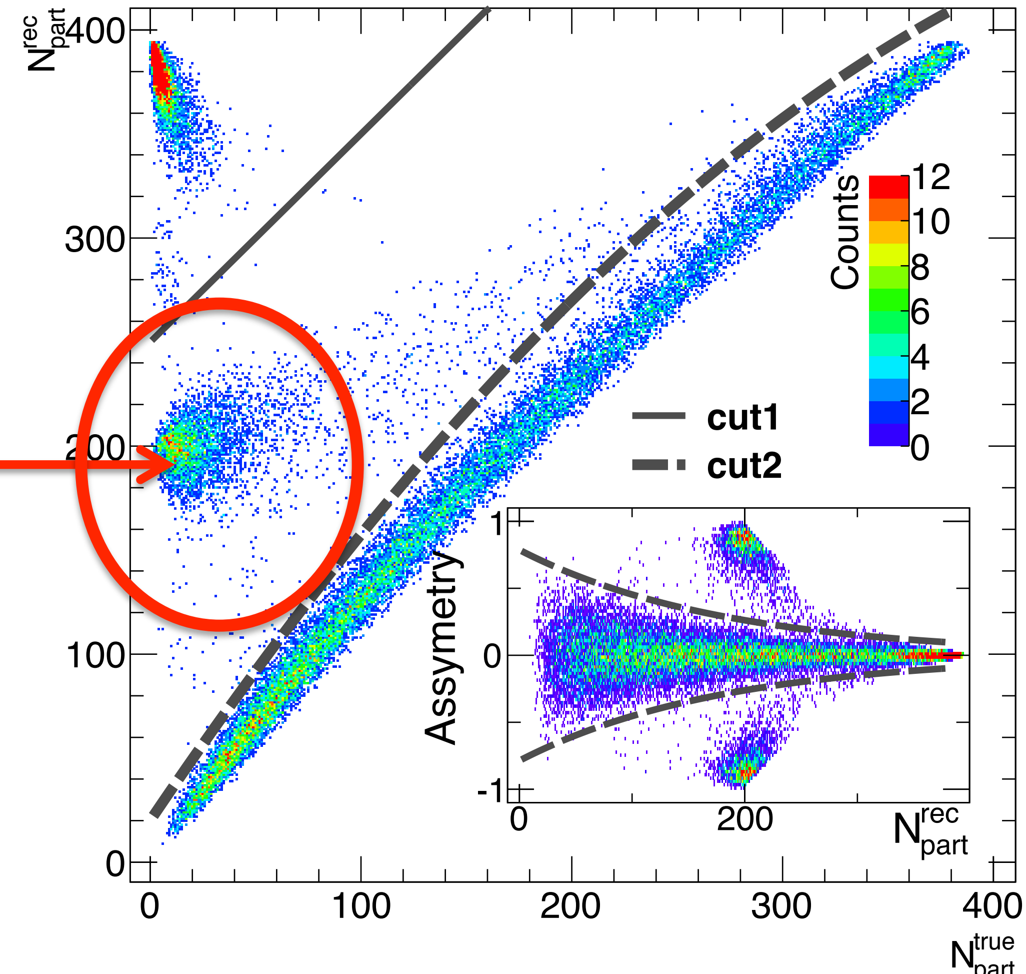


Reconstructed participants

After summing up the fragments in all stations we can calculate the number of reconstructed participants

Failed to detect a heavy fragment on both sides

Failed to detect a heavy fragment on one side



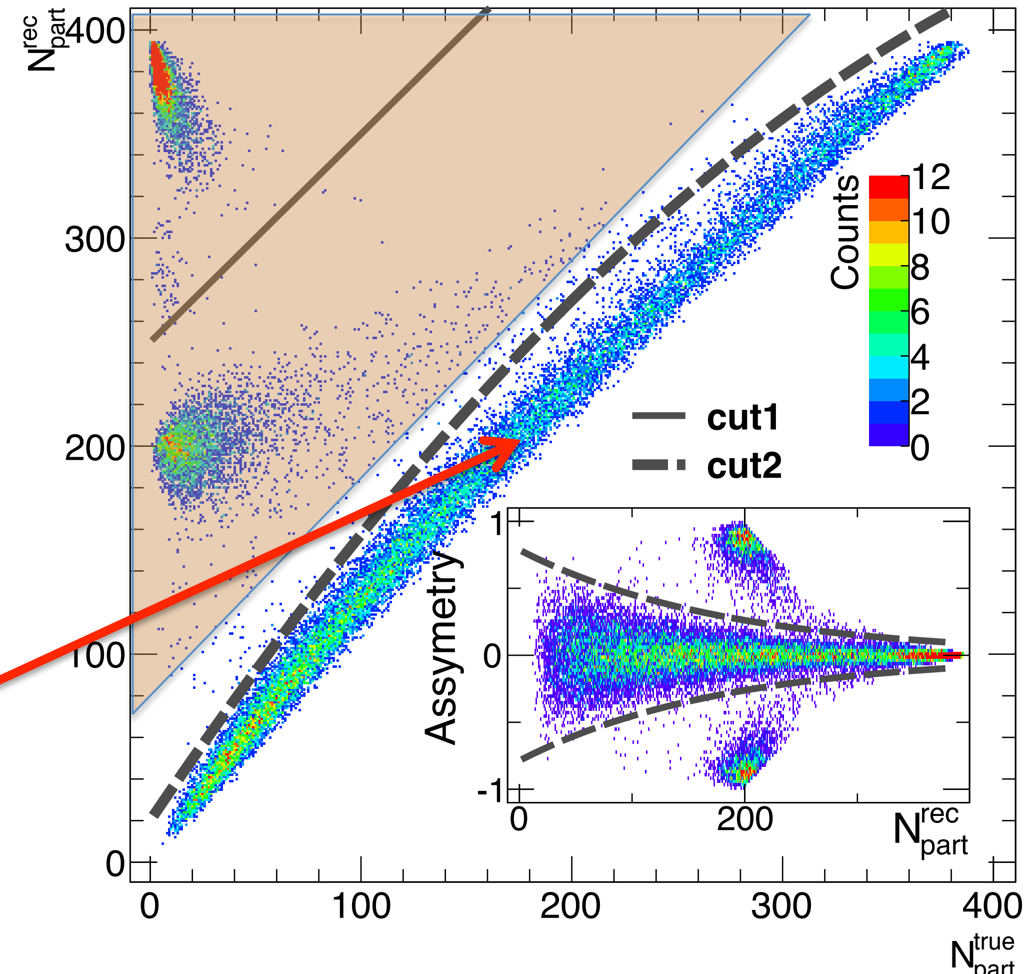
Reconstructed participants

After summing up the fragments in all stations we can calculate the number of reconstructed participants

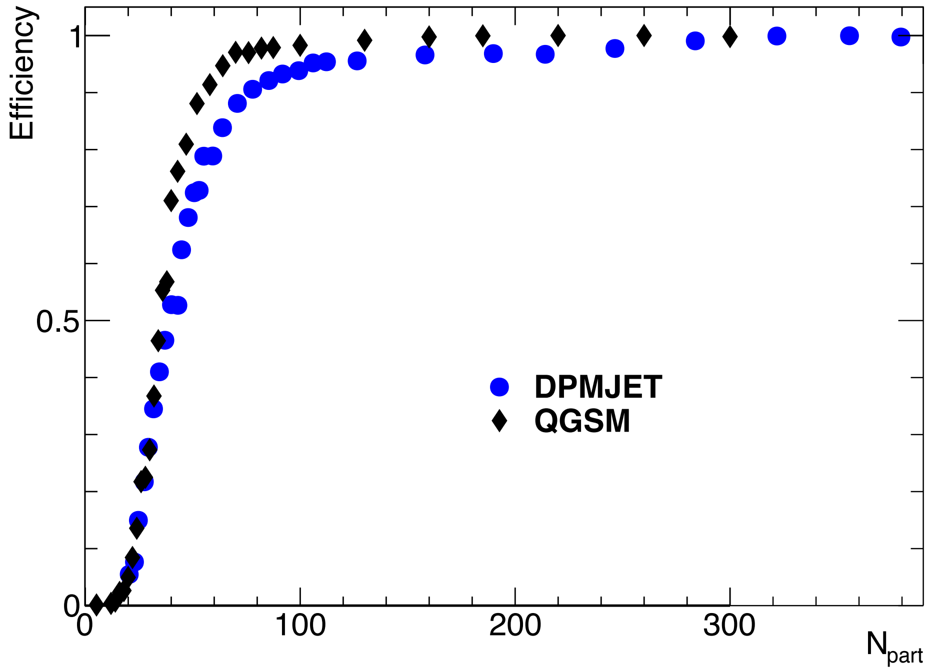
Failed to detect a heavy fragment on both sides

Failed to detect a heavy fragment on one side

Properly reconstructed events

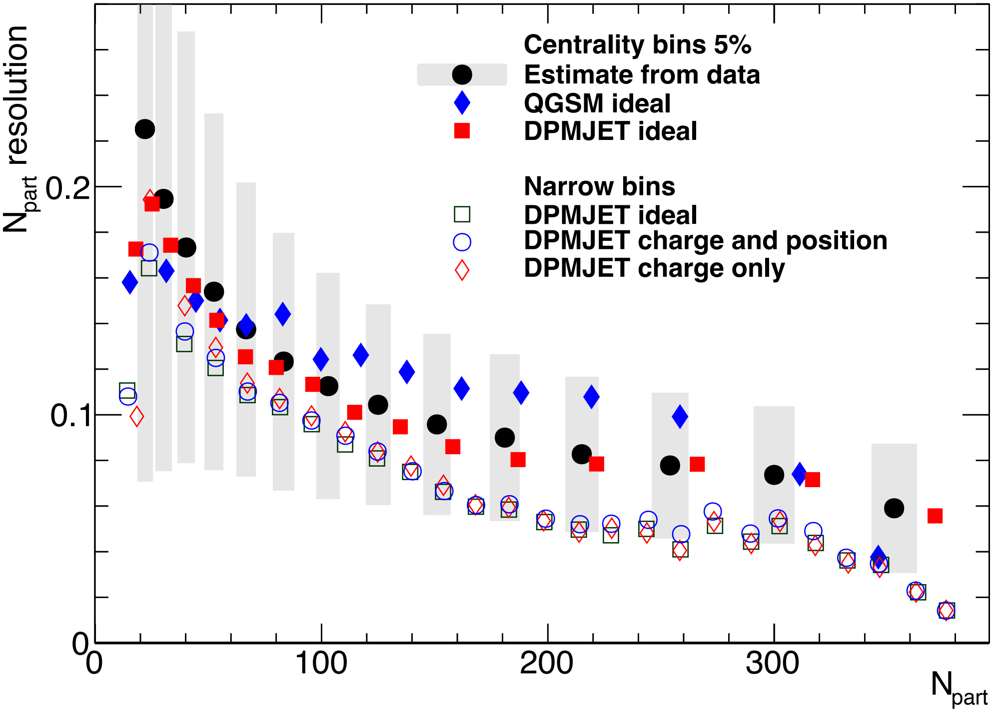


Efficiency of Centrality determination



- Centrality determination efficiency is the fraction of all events in which centrality can be determined.
- Mainly limited by Station 3 acceptance for fragments with A/Z close to 2.5.

Resolution of Centrality determination



- An event-by-event resolution: R.M.S/Mean of the N_{part} distribution vs. N_{part}.
- Filled markers are for 5% centrality intervals.
- Open markers corresponds to intrinsic detector resolution.
- Comparable to present techniques, but uses no model assumption.
- Main factor defining the resolution are the spectator missing the stations.

Detector technology: measuring charge

- Evident choice: a Cherenkov detector. Resolution to distinguish two close charges ($Z_f - 1$) and Z_f after some simplifications is:

$$\frac{dq}{q} \approx \frac{1}{\sqrt{3\langle Z_f \rangle}}$$

- Cherenkov detector with 5 cm radiator, refractive index of optical glass, 20% light collection and 10% photosensor Q.E.

Station	Typical $\langle Z_f \rangle$	Required dq/q	$\langle N_{p.e.} \rangle$
1	1 - 2	30%	20
2	20	3%	4,000
3	40	1.5%	15,000

- Number of fragments in stations is typically less than 10. The detector shall have about a hundred channels.

Detector technology : measuring x

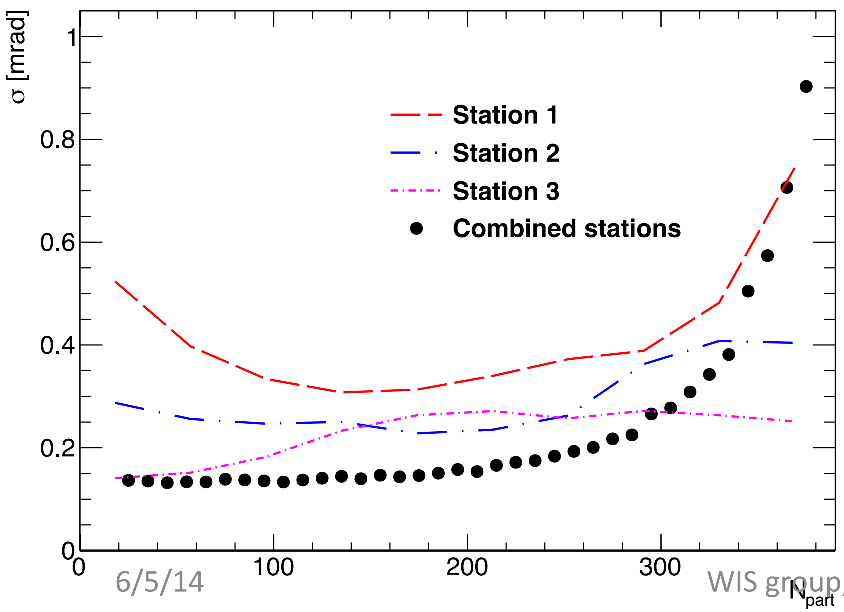
- Evident choice: Multi layered silicon pixel based tracker.
- Important for detector alignment and for background rejection by tracking particles from one station to another.
- In principle analysis of the particle angles may help to improve on A/Z accuracy and even measure the Fermi momentum p^F. That, however, may require much higher accuracy.

Further application (v_1 event plane)

- v_1 EP (Ψ_1) is typically measured done using neutron deflection in ZDC, but it can be better measured with all spectator fragment by analyzing their positions in all three stations.

- $d\Psi_1 = (\langle\sigma\rangle / \theta)\ \langle|f(\Psi)|\rangle$, θ is the polar angle of spectator fragments. $\langle\sigma\rangle$ is the resolution of spectator fragment angle at the IP.

- $f(\Psi)$ accounts for differences in σ_x and σ_y , When similar $|f(\Psi)| \sim 1$.

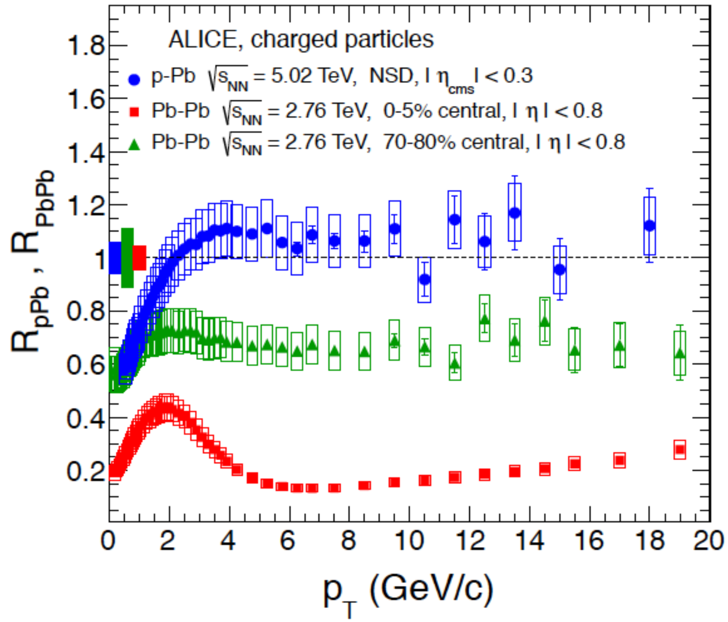


- Neutron deflection for 30-40% centrality in ALICE ZDC at 110 m is 0.92 mm [ref : Phys. Rev. Lett. 111, 232302]

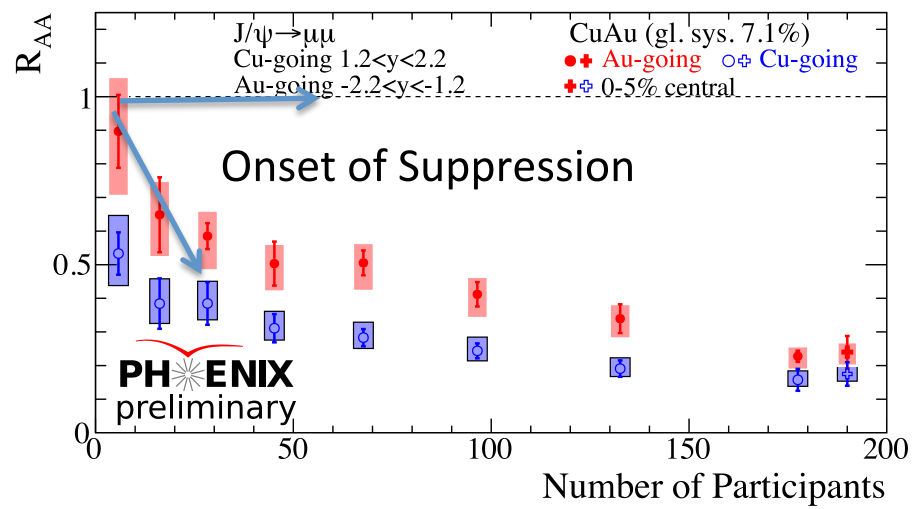
- Considering $\theta \sim 1/\sqrt{s_{NN}}$ $d\Psi_1 \sim 1.1$ rad.

Lessons from recent QM

- Smaller systems pp and pA are not that simple as we thought.
- In AA systems the onset of suppression is not understood.
- Need a direct comparison between pA and AA!



System	N_{coll}	R_{AA}	
p+p	1	--	
p+Pb	1-20	1	x15 coll – no effect
Pb+Pb	15	0.7	x15 coll – 30% effect
Pb+Pb	1600	0.2	X100 coll – 70% effect



Future improvements

- In principle this detector may allow to measure effects for same N_{part} in different systems with small systematics.

- Will play vital role in electron-Ion collision by direct measurement of spectators and hence participant nucleons.

- Detector resolutions should be improved and background should be studied.
  - Need to make detector more hermetic, measure more fragments.
  - Optimize detector station positions.
  - Understand the background coming from the upstream interactions.
  - Understanding double counting of fragments in different stations.

Conclusions

- We present concept of the detector which improves on the largest systematics in most of the heavy ion collisions, the systematics of centrality determination.
- This detector allows to measure N_{part} in model independent way and unbiased from any other measurement done in the detector.
- Detector can allow to characterize events in several other ways: measure event plane, select asymmetric events, select events with different A/Z etc.
- Detector can work in AA, pA, pp and eA systems and has different physics applications.